THE EFFECT OF AL AND B ADDITIONS ON THE OXIDATION BEHAVIOR OF ALLOYS FROM THE Nb-Cr-Si SYSTEM

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Dedication

Dedicated first and foremost to God Almighty, my source of strength. To Him be all the glory and honor. To my amazing parents, Ruben and Biviana Esparza for their love, support, hard work and for always believing in me.

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Abstract

Nickel based superalloys have been developed to perform substantially in industry however as technology develops, the need and desire to increase service temperatures to improve efficiency and performance is pushing the capabilities of these alloys. These aspired requirements entail the research and development of new structural materials that surpass the abilities of nickel alloys. Research in Nb-based alloys is underway as Nb alloys have shown to be a promising alternative with similar density but higher melting temperatures than the Ni alloys. However, because Nb has poor oxidation properties extensive studies are necessary to develop an alloy that can perform as highly as the Ni alloys in industry.

This study will focus on the effect of Al and B on oxidation resistance by subjecting five alloys from the Nb-Cr-Si system to isothermal static and cyclic conditions. Oxidation in air for 24 hours at temperatures ranging from 700°C to 1400°C has been conducted on alloys with composition of Nb-30Cr-10Si, Nb-30Cr-10Si-5Al, Nb-30Cr-10Si-10Al, Nb-30Cr-10Si-5B, and Nb-30Cr-10Si-10B (at%). The weight gain per unit area as a function of temperature was determined and samples were analyzed using SEM, EDS, XRD, and x-ray mapping. Better oxidation resistance was observed in the low temperature range in the Nb-30Cr-10Si and in alloys with boron additions. At higher temperatures, the 5Al and boron additions were beneficial to the oxidation response of the alloys. Complete oxidation occurred in all the alloys at 900°C except in the 10B alloy. The 10Al addition was detrimental at all temperatures. Alloys with boron addition yielded better oxide adherence compared to the Nb-30Cr-10Si and aluminum alloys. Cyclic oxidation for 168 hours was also performed which resulted in spalling of the oxides and limited amounts of metal left.

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Chapter 1. Introduction

New developments in high temperature technology continuously increase the need of high temperature materials and their enhanced behavior. These materials used in applications such as structural applications, turbines, energy and aerospace industry, and nuclear systems are required to withstand extreme high temperatures and maintain a suitable oxidation resistance in corrosive environments. The most capable material used in industry is nickel-based superalloys due to their high oxidation resistance in aggressive conditions under high temperatures and pressures. Although the mechanical and oxidation properties of these nickel-based superalloys have proved to be superior to any other alloys, they are gradually reaching their maximum potential due to their upper temperature limit to be used in applications. The need and desire to increase service temperatures to improve efficiency and performance will exceed the melting temperature of Ni and will require the development of new structural materials.

A promising alternative to nickel based super alloys are Niobium based super alloys because of higher melting temperatures, and low density comparable to that of nickel and high strength at elevated temperatures. Niobium however, requires development through alloying to enhance the oxidation resistance in aggressive environments and reach the performance capabilities of Ni-based superalloys. The issue with these Nb-based superalloys is that they suffer catastrophic oxidation in certain temperature range and demonstrate poor oxidation at others since niobium is highly soluble in oxygen and forms a voluminous oxide that does not offer protection to the alloy at high temperatures.[1-4]

For these reasons, extensive research has been conducted in addition of alloying elements including Al, Cr, Si, Ti, Hf, Ge, and Fe in order to enhance its oxidation resistance. These Nb-

based alloys can be processed to yield a multiphase microstructure of intermetallic phases that improve the oxidation resistance of the material. As a result of previous studies, it has been determined that through these additions the oxidation resistance of Nb-based alloys is improved but oxidation mechanisms such as pesting and spallation still remain a problem. The core of these issues deal with the phases and oxides formed during oxidation. When there is a mismatch or large difference of coefficients of thermal expansions between two phases, or a phase and an oxide, cracks tend to form and give way to the spalling and pesting mechanisms which hinder the alloys performance.

The current effort is to develop intermetallic phases such as the Laves phase that will form a protective oxide layer which will reduce the oxygen diffusion rates and decrease the oxidation of high temperature alloys in service. The Laves phase can be obtained by alloying Nb with Cr. Additionally, alloying Nb with Si result in the formation of silicides, which provide high temperature strength and improve the oxidation resistance.[5] The alloying elements that are currently of great interest include Al and B. These two elements have been reported to support the formation of an adherent, highly protective oxide scale.

The purpose of this research is to observe the oxidation behavior and kinetics of five alloys in the Nb-Cr-Si system and define the effect of Al and B on the oxidation behavior of these alloys. The Cr and Si alloying elements were selected to form intermetallic phases ($NbCr_2$) and silicides which improve oxidation resistance.[1] The addition of Al was to promote a protective Al_2O_3 layer which has been reported to highly enhance the oxide scale adhesion and decrease spalling. Boron is expected to reduce the pest susceptibility in the low temperature range.[7] The alloys selected for this study include:

- Nb-30Cr-10Si
- Nb-30Cr-10Si-5Al
- Nb-30Cr-10Si-10Al
- Nb-30Cr-10Si-5B
- Nb-30Cr-10Si-10B

A study of the effect of Al and B on the oxidation for the alloys of this system will be performed by characterizing and observing microstructural response and behavior to oxidation along with characterization of oxide scale formation. The understanding of these effects will provide a clearer perspective on the enhancement or detrimental contribution of these alloying elements in the Nb system and will add progress on the studies of Nb-based alloys.